GEOLOGY

Project title:	**Environmental and Aquatic Chemistry and Biology**
Principal investigator:	David Barkan
Phone number:	307-754-6451
Email:	*barkand@mail.nwc.whecn.edu*
Address:	Northwest College 231 West 6th Street Powell, WY 82435
Additional investigators:	Roger Clark

Objective: Mobility of metals in natural waters associated with hot springs; lead in soils and trees along roadways; genetics of plants repopulating burn areas.

Findings: No samples collected in summer of 1999.

Project title:	**An Application of Oxygen Isotope Analysis to the Genesis of Yellowstone Volcanic Rocks**
Principal investigator:	Dr. Ilya Bindeman
Phone number:	608-262-7118
Email:	*inbindem@geology.wisc.edu*
Address:	Department of Geology and Geophysics 1215 W. Dayton Ave University of Wisconsin Madison, WI 53706
Additional investigators:	John W Valley, Mike Spicuzza

Objective: Meteoric water plays a crucial role in magma genesis of Yellowstone and similar volcanics from other areas. Oxygen isotopes provide a powerful tool in deciphering the role of meteoric water. New advances in the field of oxygen isotope analyses of minerals include laser ablation of refractory minerals that were not possible to analyze using conventional techniques. Among these minerals, zircon is particularly important due to the sluggish diffusion, resistance to hydrothermal alteration, and the ability to preserve magmatic oxygen isotope.

Findings: Both quartz and zircon from volcanic rocks of different ages were analyzed for oxygen isotope ratio using laser ablation at the University of Wisconsin stable isotope lab. We also used an ion microprobe at the University of Edinburgh (Scotland) to decipher very fine scale oxygen isotope zoning in zircons. Whole rock chemical analyses for major and trace elements were made and these were correlated with oxygen isotope data.

Preliminary results of the study show a clear temporal trend of oxygen isotope evolution in both quartz and zircon. The established pattern confirms the large scale involvement of meteoric water in magma genesis, especially after the Lava Creek Tuff eruption. We now are close to proposing a new model on the genesis of low-delta-18-O rhyolites of Yellowstone after major caldera collapses. Two papers have been written and they are now in review. Further work, however, is necessary to shed the light on the details of this process, especially if reviewers will ask us to analyze a few more units, or revisit old ones.

Project title: **Investigation of CO_2 Emissions Related to the Yellowstone Volcanic/Hydrothermal System**

Principal investigator: Dr. Susan Brantley
Phone number: 814-863-1739
Email: *brantley@geosc.psu.edu*
Address: Geoscience Department
Pennsylvania State University
540 Deike Building.
University Park, PA 16802

Additional investigators: Cindy Werner

Objective: 1) To estimate the CO_2 emissions due to the Yellowstone volcanic/hydrothermal system. 2) To monitor background temporal variability of CO_2 emissions and how variations are related to changes in hydothermal and seismic activity. 3) To study the spatial distribution of CO_2 emissions and investigate controls on spatial heterogeneity of gas emissions. 4) To monitor gas chemistry including carbon and helium isotopes to gain a broader understanding of the sources of magmatic gases and interactions with the hydrothermal system.

Findings: A stratified-adaptive sampling plan was designed to estimate CO_2 degassing in Yellowstone National Park, and applied in the Mud Volcano thermal area. The stratified-component focused effort in regions with the most spatial heterogeneity (high-flux regions), without biasing our estimate for the total region. The maximum and minimum measurements for vent and diffuse fluxes were 2.4×10^9 and 6.3×10^4 mols/yr, and 32,000 and 4.0 g/m^2/day, respectively. Fluxes observed in most vegetated regions of Mud Volcano were similar to values reported by agricultural studies (<38 g CO_2/m^{2}day). However, we also found a few high-flux vegetated sites (up to 5,000 g/m^2/day) that are likely thermal features that have waned in thermal activity, yet are preferred pathways for degassing of deep CO^2. Vent degassing (2.4×10^9 mols/yr) accounts for ~50% of the total degassing observed at Mud Volcano (4.9×10^9

mols/yr). Using estimates of magma emplacement rates from other studies, we calculated a rough CO_2 flux for the entire Yellowstone system based on the relationship between heat flux and CO_2 degassing. We approximated an emission rate of 7×10^{11} mols/yr, which is comparable to globally important volcanic fluxes.

Temporal variation of CO_2 emissions was observed to correlate with soil moisture, and environmental conditions. Preliminary investigation of the CO_2 emissions in the Upper Geyser Basin, Mammoth Springs, Roaring Mountain, Washburn Springs, Crater Hills, and the Lamar River Valley suggest that diffuse degassing is highest in acid-sulfate and travertine precipitating regions, and lowest in regions of silica precipitation and sulfur flows. No attempt has been made to estimate vent emissions in these areas.

Project title: **Geochemical and Isotopic Variations in the Absaroka Volcanic Supergroup – Implications on Petrogenesis and Magma Sources**

Principal investigator: E. Lee Bray
Phone number: 708-547-7223
Email: *bray@isgs.uiuc.edu*
Address: Illinois State Geological Survey
9930 Derby Lane, Suite 103
Westchester, IL 60154

Additional investigators: Jeffrey D. Keith, Eric H. Christiansen, Stephen T. Nelson

Objective: The formation of potassic magmas related to subduction has been studied in many areas of the world but remains controversial because of the high-K and relatively low SiO_2 compositions of the rocks. During the Eocene, the Farallon Plate was subducted beneath the North American Plate and is believed to have produced magmas that erupted throughout western North America. Some of these Eocene volcanic centers erupted distinctly potassic magmas, including the Highwood Mountains, Montana; Crazy Mountains, Montana; and Two Buttes, Colorado. The reason for the high K-content (and presumably other incompatible trace elements) is uncertain, but several possibilities exist. Lavas with high-K content have been interpreted to be related to deeper subduction. Others have suggested that these potassic magmas may have had a higher proportion from a phlogopite-bearing metasomatised lithospheric mantle source with lesser asthenospheric melts triggered by subduction-related fluids during the Eocene.

The eruptions of the Absaroka volcanic supergroup in Wyoming and Montana also occurred during the Eocene, producing both potassic and calc-alkaline flows. Documenting the textural and chemical variations in the volcanic rocks of a portion of the field in the Absaroka Mountains of northwest Wyoming provides information to develop a petrogenetic model for potassic magmas. Specific questions addressed by this research include: 1) What are the compositions of the magmas? How did they vary in time and space? 2) How did the tectonic setting, magma sources, and magmatic processes affect the oxidation state of the magmas involved? 3) What were the sources of the magmas? What were the roles of the Farallon Plate that was subducted during the Eocene, ancient metasomatised mantle, or continental crustal contamination in these contrasting magma systems? 4) What role did crustal assimilation and magma mixing have in the development of the magmas? 5) How did the tectonic setting affect magma petrogenesis? 6) What new information about shoshonites can be obtained from the data?

Findings: Interpretation of chemical and isotopic (Sr and Nd) analyses of volcanic rocks in the Absaroka volcanic supergroup infer that variations in magma sources and evolutionary processes occurred for this volcanic suite. The Absaroka volcanic supergroup represents Tertiary eruptions associated with the subduction of the Farallon Plate below western North America. The mafic rocks are enriched in K and other lithophile elements. Extrusive and related intrusive rocks in the 49 to 44 Ma Absaroka volcanic supergroup are represented by the Washburn, Sunlight, and Thorofare Creek groups. This study focuses primarily on the Sunlight group from the central part of the field. The earliest flows of the Washburn and Sunlight groups were erupted in the northern and eastern portions of the volcanic field. The younger Thorofare Creek group was erupted in the southwestern portion of the volcanic field. The Sunlight Group contains a distinctive shoshonitic series and a contrasting calc-alkaline series.

Major and trace element abundances show that the magmas are not primary and that variations in the magma sources and magmatic processes occurred within each group. Magma mixing is indicated by disequilibrium textures such as resorption features and high concentrations of incompatible elements in intermediate composition rocks. The shoshonitic series is essentially tholeiitic (in terms of Fe/Mg ratios) and contrasts with the lower K and lower Fe/Mg ratios in the calc-alkaline magmas.

Important source components all of the magmas have high LILE/HFSE ratios. The enrichment of LILE may have been related to subduction contemporaneous with magma formation, or it may have been the result of subduction processes during the Archean when the basement formed. Evidence for both processes is present in the Absaroka volcanic supergroup. The isotopic signatures of Sr and Nd in Sunlight group flows and dikes suggest a mixing of magmas from ancient phlogopite bearing lithospheric mantle (such as the base of the Wyoming Craton) and asthenospheric sources. The flows of the Washburn and Thorofare Creek Groups have higher initial $^{87}Sr/^{86}Sr$ values, which are interpreted to be from assimilation of crustal material, but eNd values are still negative, suggesting that contributions of lithospheric mantle with asthenospheric mantle were also important.

Modeling of shoshonitc melts infer that orthopyroxene fractionation at high pressures did not produce the K enrichment characteristic of shoshonites. The calc-alkaline series identified in the Absaroka volcanic supergroup did not evolve from the shoshonitic magmas, but may have had common source components. The plagioclase + clinopyroxene + olivine + magnetite ± apatite assemblage observed in the shoshonitic samples indicates low pressure crystallization of a magma with a high initial K content.

Project title: **The Search for Microbial Biomarkers in Terrestrial Deposits**

Principal investigator: Dr. Henry Chafetz
Phone number: 713-743-3427
Email: *HChafetz@uh.edu*
Address: Department of Geosciences
University of Houston
Houston, Texas 77204-5503

Additional investigators: Sean Guidry

Objective: The primary purpose of this investigation is to evaluate the fossilization process and the potential for a long term record of the microbial life that exists associated with hot springs and their carbonate (travertine) and siliceous (siliceous sinter) deposits. Basically, we are looking for biomarkers, indicators that microbes once existed as part of the hot spring environment. This will allow us to determine the likelihood of finding fossilized microbes in extraterrestrial bodies (e.g., Mars) and what is the most likely preserved material. For example, will we have a better chance of finding body fossils or geochemical indicators of former organisms? In order to carry out this investigation, we have and will continue to analyze the waters from which the minerals precipitates originate as well as the precipitates of carbonate (Mammoth Hot Springs) and siliceous sinter (Cistern Spring, Norris Geyser Basin). It is our intent to search for mineralogical (crystal habit, size, etc.) and geochemical (major, minor, and trace elements as well as isotopic) differences between biotically induced and abiotic precipitates as well as microbial remains (bacterial body fossils, biofilms, etc.).

Findings: Our work to date has indicated that biogenic compounds appear to breakdown relatively quickly in this hot environment and thus will not be well preserved in the ancient record. Some body fossil types, however, seem to display relatively good preservation potential. Samples are being curated in our department collections. Descriptions of the samples in the collection were previously forwarded.

Project title: **Geochemical Baselines in the Greater Yellowstone Area**

Principal investigator: Dr. Maurice Chaffee
Phone number: 303-236-1855
Email: *mchaffee@helios.cr.usgs.gov*
Address: U.S. Geological Survey
Federal Center MS 973
Denver, CO 80225-0046

Additional investigators: Daniel R. Norton, William Miller, Harley King, Richard Sanzolone

Objective: 1) Provide objective, unbiased geochemical baseline data for about 50 chemical elements determined in samples of rock, active stream-sediment, water, plants, and animal scat collected from scattered localities throughout Yellowstone National Park and the adjacent U.S. Forest Service lands. Baselines to include raw data and interpretive reports. 2) Identify the sources, such as geothermal features, past mining, and recreation, of anomalous concentrations of selected elements. 3) Determine the chemistry of selected elements in the food chain and how these elements may impact the health of wildlife in the park.

Findings: Samples of stream sediment, rock, water, and/or animal scat have been collected from as many as 555 sites in and around YNP. These samples have been analyzed for as many as 50 elements. In the northeastern part of the park, weakly anomalous levels of elements related to mineralized rock or to past mining in the Cooke City area have been detected in samples from the Soda Butte Creek drainage basin. These weak anomalies extend to the confluence of Soda Butte Creek with the Lamar River, where sediments from that stream with background levels dilute the anomalous concentrations from Soda Butte Creek to background levels.

In the geothermal areas of the park studied to date (both fossil and active), a common suite of elements is generally present in sediment downstream from each area. Concentrations for some elements, such as arsenic and fluorine, are significantly elevated as compared to background element levels. Cesium seems to be the best unique indicator of geothermal activity.

Analysis of 62 samples of elk or bison scat shows anomalous concentrations of elements associated with geothermal features for those animals grazing near such features, indicating that animals browsing in geothermal areas are ingesting significant levels of elements such as arsenic and fluorine. The effect of fluorine on elk and bison has been documented by others. The effects of other elements on elk or other animals is not known. Sampling is continuing to better define and understand the sources of anomalies and the possible impacts of various elements on park animals.

Project title: **Volcanology and Petrology of the Yellowstone Plateau Volcanic Field**

Principal investigator: Dr. Robert L. Christiansen
Phone number: 650-329-5201
Email: *rchris@mojave.wr.usgs.gov*
Address: U.S. Geological Survey
345 Middlefield Rd., MS910
Menlo Park, CA 94025

Additional investigators: Wes Hildreth

Objective: To understand the origins and eruptive mechanisms of late Cenozoic volcanic activity in the region of Yellowstone National Park and to complete systematic geologic-mapping studies carried out intermittently in the park region since the 1960s.

Findings: No new work was done on this project in 1999. USGS Professional Paper 729-G is now nearly ready for publication by the USGS Western Publications Group, but still awaits final digital details on the largest geologic-map plates.

Project title: **Geochemistry and Geochronology of Eocene Potassic Volcanism in the Absaroka Volcanic Field**

Principal investigator: Dr. Todd Feeley
Phone number: 406-994-6917
Email: *tfeeley@montana.edu*
Address: Department of Earth Sciences
Montana State University
Bozeman, MT 59717

Additional investigators: Charles Lindsay, Julie Hamblock

Objective: Our objective is to carry out a geological and geochemical transect across the northern part of the Eocene Absaroka volcanic field. Because the Absaroka volcanic rocks record one of the most voluminous and compositionally diverse magmatic episodes to affect the Cordillera during the Eocene, the results obtained from this study will improve our knowledge of the ages, compositions, and petrogenesis of Tertiary magmatism in the northern Rocky Mountains. This, in turn, will provide insight into the fundamental problem of how rock suites with arc-like geochemical features can form in such different tectonic environments and possibly in the absence of contemporaneous subduction. The targeted areas in Yellowstone National Park are the Mt. Washburn-Observation Peak volcanic center, the Sepulcher Mountain-Electric Peak eruptive center, and the Sylvan Pass-Eagle Peak eruptive center.

Findings: Our work in the Washburn Range during the previous year is summarized as follows. Volcanic rocks in the southwest Washburn Range erupted on the flank of the Mount Washburn volcano; a major Eocene (~54-52 Ma) eruptive center in the western calc-alkaline belt of the AVP. Rocks examined are crudely bimodal, including ol+cpx basaltic andesites and mafic andesites (52-58 wt% SiO_2) and amph (±bio) dacites (63-67 wt% SiO_2); intermediate compositions are rare. Silicic rocks are restricted to low stratigraphic levels, whereas mafic magmas are present at higher levels. These relationships contrast with those at Mount Washburn proper, the central edifice of the Washburn volcano, where 2-pyx andesites dominate and fill the gap in the southwest Washburn Range suite. For the volcanic system as a whole, major element compositions demonstrate that the rocks represent a true "calc-alkalic" suite (Peacock index ~ 60).

The mafic andesitic magmas were generated from basaltic andesitic parent magmas by varying degrees of mixing with silicic melts derived by crustal anatexis plus small degrees of fractional crystallization. Incompatible trace-element contents are elevated (Rb = 24-64 ppm; Ba = 590-1550 ppm) and define linear trends on SiO_2 variation diagrams. Compatible trace elements are also elevated (Ni = 134-14 ppm; Cr = 422-33 ppm), but trends are more diffuse than for incompatible elements. Chemical models require fractionation of minor amounts (<5%) of olivine and clinopyroxene in mafic magmas prior to or during mixing. Cross-over patterns on chondrite normalized REE diagrams (La/Yb n = 5-17) support the mixing model and, along with increasing Sr/Y with decreasing Y, suggest the silicic melts were produced at deep crustal levels where garnet was stable.

The field and geochemical relationships suggest initial development of small silicic magma bodies beneath the Washburn region due to intrusion of basalt into the lower continental crust. With time, magma supply rates probably increased and became more focused beneath the core of the Washburn volcano, developing a zone of large-scale mixing. On the periphery of the system, magma supply rates were probably lower, allowing fractionated mafic magmas to ascend and interact less with silicic magmas.

Project title: **Aqueous-Solid Geochemical Process Model of Travertine Precipitation at Angel Terrace, Mammoth Hot Springs**

Principal investigator: Dr. Bruce Fouke
Phone number: 217-244-5431
Email: *fouke@uiuc.edu*
Address: Department of Geology
University of Illinois
1301 W. Green Street
Urbana, IL 61801

Additional investigators: George Bonheyo, Craig Bethke

Objective: This research will develop a conceptual and quantitative model that identifies the abiotic and biotic processes controlling the deposition of travertines at Angel Terrace, Mammoth Hot Springs. Travertines form where carbonate minerals precipitate near the vents of terrestrial hot springs, and they record important information on water chemistry, hydrologic transport, climate, and microbial populations. There are, however, no systematic studies that offer guidance on how to interpret the complex crystalline fabrics and chemistries inherent to hot spring travertines. The process model developed in this proposal will considerably improve our ability to extract environmental information from ancient travertines by directly linking crystalline fabric and chemistry to aqueous processes within an environmental framework.

Findings: Petrographic and geochemical analyses of travertine-depositing hot springs at Angel Terrace have been used to define five depositional facies along the spring drainage system. Spring waters are expelled in the vent facies at 71 to 73° C and precipitate mounded travertine composed of aragonite needle botryoids. The apron and channel facies (43-72° C) is floored by hollow tubes composed of aragonite needle botryoids that encrust sulfide-oxidizing *Aquificales* bacteria. The travertine of the pond facies (30-62° C) varies in composition from aragonite needle shrubs formed at higher temperatures to ridged networks of calcite and aragonite at lower temperatures. Calcite “ice sheets”, calcified bubbles, and aggregates of aragonite needles ("fuzzy dumbbells") precipitate at the air-water interface and settle to pond floors. The proximal-slope facies (28-54° C), which forms the margins of terracette pools, is composed of arcuate aragonite needle shrubs that create small micro-terracettes on the steep slope face. Finally, the distal-slope facies (28-30° C) is composed of calcite spherules and calcite "feather" crystals.

Despite the presence of abundant microbial mat communities and their observed role in providing substrates for mineralization, the compositions of spring-water and travertine predominantly reflect abiotic physical and chemical processes. Vigorous CO_2 degassing causes a +2 unit increase in spring water pH, as well as Rayleigh-type covariations between the concentration of dissolved inorganic carbon and corresponding $d^{13}C$. Travertine $d^{13}C$ and $d^{18}O$ are nearly equivalent to aragonite and calcite equilibrium values calculated from spring water in the higher-temperature (~ 50-73° C) depositional facies. Conversely, travertine precipitating in the lower-temperature (< ~ 50° C) depositional facies exhibits $d^{13}C$ and $d^{18}O$ values that are as much as 4 less than predicted equilibrium values. This isotopic shift may record microbial respiration as well as downstream transport of travertine crystals. Despite the production of H_2S and the abundance of sulfide-oxidizing microbes, preliminary $d^{34}S$ data do not uniquely define the microbial metabolic pathways present in the spring system. This suggests that the high extent of CO_2 degassing and large open-system solute reservoir in these thermal systems overwhelm biological controls on travertine crystal chemistry.

Microbes and biofilms are entombed within the Angel Terrace travertine. Preliminary results reveal that both modern and ancient travertine contains abundant microbial organic matter entombed between crystals and in fluid inclusions. Comparison of microbial composition and crystal chemistry are being made between the modern and ancient travertine at Mammoth Hot Springs (0 to ~8,000 ybp) with the intent of defining fossilization potential. The identity of the travertine microbes is being approached using microscopy and 16S rRNA gene sequencing. Travertine samples collected for this study are being reposited in the research collection of the Department of Geology at the University of Illinois Urbana-Champaign.

Project title: **Geochemistry of Hot Spring Sinters and Microbial Mats**

Principal investigator: Dr. Nancy Hinman
Phone number: 406-243-5277
Email: *Nancy_Hinman@nps.gov*
Address: P.O. Box 168
Yellowstone, WY 82190

Additional investigators: Cindy Wilson, Bill Cooper

Objective: 1) Investigate geochemical variations in microbial mats, pore waters, siliceous sinters, and geyserites at different hot springs and thermal drainages in the park. Results will be compared with stage of silica diagenesis and geochemistry. 2) Investigate the local hydrogeological characteristics of hot spring-influenced drainages. Results will be used to calculate mass balances for such drainages, to determine silica deposition rates in sinter mounds and to determine interaction with local groundwater. 3) Investigate photochemical processes in thermal springs of various composition.

Findings: Photochemical studies on the production of hydrogen peroxide and the redox cycling of iron continued this year. Field studies with Dr. Lynn Rothschild were conducted in July. A field reconnaissance of sites with new collaborator, Dr. Bill Cooper was conducted in September.

Research efforts focused on determining chemical characteristics that control the production of hydrogen peroxide in thermal springs. Absorbance is a critical process in any photochemical reaction. The absorbance spectra of hot spring waters, treated in various ways, were collected. Absorbtivity (abs/cm) were calculated from the absorbance spectra. The values were lower than for other surface waters. The absorbtivity is used to calculate the quantum yield for a given reaction. Calculations of the quantum yield for hydrogen peroxide in thermal waters indicate that the number of moles of hydrogen peroxide produced per mole of photons absorbed is five to ten times higher in these thermal waters than other surface waters. This is an important finding because it suggests that hydrogen peroxide can be produced in significant quantities although the waters are fairly nonabsorbent. Light is not greatly attenuated with depth, thus there is potential for hydrogen peroxide to form over several meters depth. As a consequence, the environment of thermal springs may be harsher than previously thought.

Studies were conducted on the distribution of aluminum in siliceous sinters from Pott's Basin and Excelsior Crater, Midway Geyser Basin. As a trace constituent, its distribution is controlled by changes in fluid composition along a flow path. Preliminary results suggest that precipitated aluminum is concentrated in the interiors of microbial filamental fragments in some thermal springs but not others.

Project title: **Digital Quaternary Map of Wyoming including Yellowstone**

Principal investigator: Cheryl Jaworowski
Phone number: 307-766-2721
Email: *jaworow@uwyo.edu*
Address: Spatial Data & Visualization Center
University of Wyoming
Laramie, WY 82071

Objective: Field checking of Quaternary stratigraphic sites was conducted as part of the University of Wyoming's Summer Research Apprentice Program. In Yellowstone National Park, the University of Wyoming team examined deposits and logged digital coordinates of 44 Quaternary stratigraphic sites. The YNP stratigraphic sites in the Canyon area and along the north and west shores of Yellowstone Lake are part of a digital data layer for a Quaternary geologic map of Wyoming.

More than 70 stratigraphic sites exist statewide. In addition to the digital map and Quaternary stratigraphic sites, information about Quaternary faulting, sediment descriptions, geochemistry of volcanic ashes, locations of relict periglacial wedges, a correlation chart, and bibliography are being compiled from previously published maps, field guides, and scientific publications. The digital Quaternary geologic map of Wyoming will be a one-stop source of information available on the Wyoming Internet Map Server (*http://wims.sdvc.uwyo.edu*). The preliminary digital Quaternary geologic map of the entire state of Wyoming (including Yellowstone) will be available for viewing later this year.

Findings: Forty-four Quaternary stratigraphic sites in Yellowstone were examined for the Yellowstone portion of the digital Quaternary geologic map of Wyoming. Quaternary stratigraphic sites were visited in the Grand Canyon of the Yellowstone, Hayden Valley, and along the west and north shores of Yellowstone Lake. The purpose of this reconnaissance was 1) to field check the Yellowstone map units; 2) to obtain GPS locations of important Quaternary stratigraphic sites using a Trimble Pro XRS receiver; and 3) to examine various Quaternary sediments for map units descriptions.

On the north shore of Yellowstone Lake, volcanic ash was collected from two locations: Fishing Bridge; and Indian Pond. Samples were prepared for geochemical analysis according to the techniques described by Sarna-Wojcikcki and others (1984). After dry sieving, chemical preparation, and magnetic separation, the Fishing Bridge ash was primarily glass shards. The Indian Pond ash still requires the use of heavy liquids to further concentrate the glass shards. The Fishing Bridge geochemistry (weight %) shows an Fe_2O_3/CaO ratio that is consistent with known G-type rhyolitic glasses. Fe/Ca ratios of Yellowstone-source ashes fall within the G-type rhyolitic field on an Fe-Ca plot. The Indian Pond ash is a non-Yellowstone volcanic ash. Further laboratory and geochemical work is needed on the Indian Pond volcanic ash and samples of Yellowstone volcanic ashes found in Quaternary deposits throughout Wyoming.

Project title: **The Structure, Facies, and Deposition of Siliceous Sinter around Thermal Springs: Implications for the Recognition of Early Life on Earth and Mars**

Principal investigator: Dr. Donald Lowe
Phone number: 650-725-3040
Email: *lowe@pangea.stanford.edu*
Address: Department of Geology
Stanford University
Stanford, CA 94305-2115

Objective: 1) To study the textures and structuring of siliceous sinters deposited around hot springs and to determine the physical and chemical controls on sinter deposition. 2) To characterize the role of thermophilic organisms in sinter deposition. 3) To compare the structure of sinter with that of putative biological structures in the oldest sedimentary rocks on Earth. 4) To evaluate which features of sinter are diagnostic of biological influences to aid in possible identification of organisms during planetary exploration.

Findings: Our investigations to date have focused on the hydrodynamic controls on the structuring and morphology of siliceous sinter facies around alkaline hot springs and geysers in Yellowstone. Our work can be divided into two sub-studies: 1) an investigation of low-temperature (less than 73° C) sinter facies, where cyanobacterial mats play a significant role in the structuring and development of sinter at all observational levels; and 2) an investigation of high-temperature (greater than 73° C) sinter facies where thermophilic bacteria may play a role in mediating silica precipitation rates and influence microstructuring and microtextures, but where hydrodynamics are the primary control on the development of sinter macrostructures. Ph.D. student Deena Braunstein completed her Ph.D. study of high-temperature sinter in Yellowstone and graduated from Stanford in June 1999. Her thesis includes three chapters dealing with: 1) the hydrodynamic behavior and structuring and morphology of siliceous sinter deposited around a variety of alkaline siliceous hot springs and geysers; 2) the microscopic structuring and deposition of siliceous sinter; and 3) a case study of sinter deposited around Coral Pool (Shoshone Geyser Basin). Dr. Lowe visited YNP in September 1999 and continued his investigations at Steep Cone Spring, which has been a site of detailed photo-documentation of sinter growth rates for several years. In addition, growth-rate experiments were at the Buffalo Pool Group, Five Sisters Springs, and Fountain Paint Pots area.

The principal activities for 1999 consisted of monitoring sinter growth-rate experiments at Steep Cone Spring, Fountain Paint Pots area, Buffalo Pool Group, and the Five Sisters Group. Additional experiments installed at Coral Pool in Shoshone Geyser Basin in 1998 were left intact and not visited in 1999. These experiments are part of a long-term study of sinter growth rates.

Project title: **Mine Impacts on Stream Morphology, Microhabitats, and Riparian Ecology**

Principal investigator: Dr. W. Andrew Marcus
Phone number: 406-994-6915
Email: *amarcus@montana.edu*
Address: Department of Earth Sciences
Montana State University
Bozeman, MT 59717

Additional investigators: Robert Ahl, Ed Schrader, Jamie Harris

Objective: The objective of this research is to determine the distribution of metals from mining in sediments of a riparian system, investigate the processes controlling those distributions, and determine the biotic impacts associated with the metals. The investigation focuses in Soda Butte Creek, which experienced mining in its headwaters up until 1953.

Findings: Mine-derived metals in sediments of the active channel display a decrease in the downstream direction due to dilution by cleaner sediments from tributaries. Recent floods in Soda Butte Creek have not cleaned the system because exposed mine waste is washed into the creek at the same rate as clean sediments, leading to no net decrease in metal concentrations. Metals in the bed sediments are depressing macroinvertebrate populations. Metals in floodplain soils are reducing grass biodiversity, biomass, and density. Ongoing studies will monitor heavy metal levels and macroinvertebrate populations to determine long-term changes and recovery of the system.

Project title:	**Volcano Emissions**
Principal investigator:	Kenneth McGee
Phone number:	360-993-8931
Email:	*kenmcgee@usgs.gov*
Address:	U.S. Geological Survey Cascades Volcano Observatory 5400 MacArthur Boulevard Vancouver, WA 98661
Additional investigators:	Terrence Gerlach, Michael Doukas, Richard Kessler

Objective: Survey and characterize carbon dioxide emissions from Yellowstone soils and thermal areas in order to identify possible areas of anomalous degassing from depth and to provide a baseline with which to compare future surveys of carbon dioxide in the event of volcanic unrest. The study involves airborne measurements of carbon dioxide and other gases in the air above the park as well as ground measurements of carbon dioxide soil efflux within the park.

Findings: Several areas of carbon dioxide efflux have been measured within the park that are greater than what would be expected from normal biologic activity in the soil. In addition, several carbon dioxide plumes from various sources within the park were successfully measured in the air above the park in 1998 and 1999 utilizing sensitive instrumentation mounted in fixed-wing aircraft. Similar measurements utilizing helicopters as the airborne platform are anticipated. The detailed analysis of data is not yet complete.

Project title:	**Holocene and Modern Geomorphic Response to Fires, Floods, and Climate Change in Yellowstone National Park – Natural and Anthropogenic Influences on Stream Systems**
Principal investigator:	Dr. Grant Meyer
Phone number:	541-346-4557
Email:	*gmeyer@oregon.uoregon.edu*
Address:	Geography Department 107 Condon Hall University of Oregon Eugene, OR 97403-1251
Additional investigators:	Paula M. Watt

Objective: To provide a long-term perspective on the geomorphic impacts of the 1988 Yellowstone fires, we are investigating Holocene sedimentation in northeast Yellowstone using post-1988 fire-related events as a guide for interpretation of alluvial fan stratigraphy. Comparison of the timing of fire-related events with climate proxy records elucidates the relative controls of climate, fire, and intrinsic geomorphic thresholds on alluvial systems. We are also documenting extreme floods of the last ~300 years and their effects on valley floor landscapes of northeast Yellowstone. Recent changes in stream channels seen through analysis of air photos, historical photos, and re-surveying are evaluated in the context of flood history, riparian vegetation and ungulate browsing, and intrinsic characteristics of basins and channels. We are also studying a 1950 dam failure at Cooke City, Montana, that deposited acidic, metal-rich mine tailings along the Soda Butte Creek floodplain.

Findings: Our study of the geomorphic response to fires is largely complete, and shows that fire is both an important catalyst for landscape change and is strongly controlled by climate on 100-1000 year time scales. Ongoing study has identified major floods in the Lamar River system in 1918, the early 1870s, and possibly near 1800. These floods had much greater peak discharge than the 1996 and 1997 floods (the largest in gauge records), and their extensive dry gravelly deposits have lasting impacts on stream channels and valley floor ecosystems. The 1950 tailings dam break produced extreme discharges but had short duration, and thus caused little erosion. However, tailings deposits along Soda Butte Creek have significant copper and lead content, impact floodplain vegetation, and continue to be eroded into the channel, adding to mining-related metal pollution.

Project title: **Redox Processes Controlling Arsenic Mobility in the Hyporheic Zone**

Principal investigator: Dr. Johnnie Moore
Phone number: 406-243-6807
Email: *gl_jnm@selway.umt.edu*
Address: Geology Department
32 Campus Drive #1296
Missoula, MT 59812-1296

Objective: To determine the role that the hyporheic zone (the zone just beneath the bed in a stream) plays in mobilizing arsenic from sediments enriched in arsenic.

Findings: Unfortunately, we were not able to conduct research on this project because none of our funding sources came through. We did no sampling and no work of any kind in the park during 1999.

Project title: **Sulfur Speciation and Redox Processes in Mineral Springs and their Drainages**

Principal investigator: Dr. Kirk Nordstrom
Phone number: 303-541-3037
Email: *dkn@usgs.gov*
Address: U.S. Geological Survey
3215 Marine Street
Boulder, CO 80303-1066

Additional investigators: Martin Schoonen, Gordon Southam

Objective: The primary objectives are to determine the actual speciation of dissolved sulfur species as they undergo oxidation and volatile losses for H_2S, and to study the evolution of acidic drainages unaffected by pyrite oxidation. Intermediate sulfoxy anions such as thiosulfate have been implicated as complexing agents to solubilize and mobilize metals in the formation of ore deposits and as monitors of volcanic activity. We hope to relate sulfur speciation in hot springs and their overflow drainages to rates of oxygen diffusion and solubility. We also hope to learn how the chemistry of acidic drainages dominated by elemental sulfur oxidation differs from those dominated by pyrite oxidation.

Findings: Two USGS open-file reports containing analyses of 99 hot spring, geyser, and surface water samples from 1974-75 sampling and 42 samples from 1994-95 sampling have been published in 1998 and are available for free from the senior investigator. A report on water analyses collected during 1996-98 will be available later this year. A scientific paper summarizing the occurrence and interpretation of thiosulfate in Yellowstone waters has been published and a detailed study of the formation and decomposition of sulfur species in Cinder Pool is in press. During the 1999 field season, 30 water samples were collected from Norris Geyser Basin and six samples from Brimstone Basin. Sampling and on-site analysis was made possible with a mobile laboratory equipped with an ion chromatograph, a portable UV-visible spectrophotometer, and an autotitrator. New hot springs suddenly appeared in the Ragged Hills area of Norris in late spring/early summer of 1999 and these were sampled for all major ions and most trace elements in September. In addition, all the samples from Norris were analyzed for arsenic redox species, i.e., As(III/V). The preliminary and unexpected results indicate that all samples have some As(V), the amount of As(V) seems to correlate with the amount of exposure to air or oxygenated groundwaters, and surface drainages from hot springs are mostly oxidized to As(V). This rapid oxidation is presumed to be caused by microbial catalysis and *Thiobacillus thiooxidans* has been identified in these waters.

Project title: **Quaternary Geology, Geo-Ecology, Geoarcheology, Neotectonics, and Hazards Studies of the Greater Yellowstone Area**

Principal investigator: Dr. Kenneth Pierce

Phone number: 303-236-1244
Email: *kpierce@usgs.gov*
Address: U.S. Geological Survey, MS 980
Box 25046, Federal Center
Denver, CO 80401

Additional investigators: Ken Cannon, Lisa Morgan, Don Despain, Pat Shanks

Objective: 1) Investigate Yellowstone Lake and river level changes associated with caldera inflation/ subsidence cycles. 2) Geoarcheology of sites, particularly around Yellowstone Lake. 3.) Hazards appraisal, particularly late Quaternary faulting, hydrothermal explosions, volcanism, and landsliding. 4) Outreach, including books, training videos, and high quality videos on Yellowstone geology. 5) Relationships between geology and ecology, particularly the meadow-forest contrast. 6) Investigate Crevice Lake as a coring site and develop proposals for coring and developing information from cores. 7) Investigate and write up relations between Yellowstone hotspot and associated volcanism, faulting, and uplift and broad scale ecological relations in the Greater Yellowstone Area.

Findings: Rhyolitic hotspot volcanism constructed the Pleistocene Yellowstone Plateau. Streams eroding the steep edges of this plateau form scenic canyons and waterfalls. Rhyolite is poor in nutrients and forms sandy, well-drained soils that support the monotonous, fire-prone, lodgepole pine forest of the Yellowstone Plateau that contrasts with the more varied vegetation, including spruce-fir and whitebark pine forests broken by grassy meadows on the bedrock and surficial materials that flank this plateau. Upwelling waters heated by hotspot magmas drive Yellowstone's famed geysers, hot springs, and mudpots, which provide habitat for specialized, primitive ecosystems of algae and bacteria.

Basin-and-range faulting has accompanied migration of the hotspot to Yellowstone, forming linear ranges and valleys on both sides of the hotspot track of the eastern Snake River Plain. Hotspot-associated faulting forms a distinctive part of the GYE, with characteristic rugged, forested ranges and adjacent flat-floored grassy valleys. The contrast in altitude from the basins up through the adjacent ranges is important to the ecosystem and provides a year-round environment for various and cyclic annual migration paths and seasonal upward migration in maturation of vegetation. The valleys provide natural meadows, agricultural land, town sites, and corridors for roads.

Recent uplift to form the Yellowstone crescent of high terrain has also resulted in ongoing erosion of deep, steep-walled valleys in readily erodible rock. Modern and Pleistocene weather and resultant vegetation patterns strongly relate to crescent of high terrain and the of the Snake-River-Plain track. Moist Pacific air masses traverse the Snake River Plain and rise onto the Yellowstone Plateau and then the crescent of high terrain and produce deep orographic snows, and east of the mountains, a precipitation shadow. Such deep orographic snows nourished extensive Pleistocene glaciers that covered the core GYE and produced many of the landscape features on which modern soils have formed, including gravelly outwash plains covered with sagebrush-grassland and silty lake sediments commonly covered by lush grassland such as Hayden Valley.

Human settlement and use of the GYE reflects the hotspot processes of uplift, volcanism, and faulting. Uplift formed a remote highland from which streams drain radially outward like spokes from a hub. Along these radial drainages humans have settled around Yellowstone, established roads, irrigation systems, and political associations. Decision making involving the GYE is complicated by multiple jurisdictions athwart this hotspot highland, including 18 counties, seven national forests, three states, and two national parks.

In 1999, I prepared a field guide and co-led with Don Despain an interdisciplinary field trip through different habitat areas of Yellowstone. Many relations between surficial geology, soils, and vegetation were discussed. Although much of Yellowstone is forested, a strong correlation exists between fine-grained surficial materials and meadows, which are one of the most important features in Yellowstone's ecology. The critical factor appears to be fine-grained soil matrix holding most snowmelt water at shallow depths, thus favoring herbaceous vegetation.

Project title: **Operation and Development of an Earthquake and Volcano Information System at Yellowstone (YSGN) and Ancillary Research on the Geodynamics of the Yellowstone Hotspot**

Principal investigator: Dr. Robert B. Smith
Phone number: 801-581-7129
Email: *rbsmith@mines.utah.edu*
Address: University of Utah
Department of Geology and Geophysics
135 So. 1460 East, Rm. 702
Salt Lake City, UT 84112

Additional investigators: Charles Meertens

Objective: The primary objective of the Yellowstone earthquake and volcano information system is to operate the Yellowstone seismic and GPS networks (YSGN) necessary to monitor seismicity and ground deformation that may be related to both volcanic and tectonic earthquake activity. In addition, ancillary research funded by the National Science Foundation titled "Geodynamics of the Yellowstone hotspot" use the data and support in part the student and faculty research described herein. The data acquisition component of our project include maintenance, recording, routine analyses and installation of seismic and GPS instruments in and around Yellowstone National Park. Data from the YSGN provide information for public safety, NPS management and planning, access of GPS information for surveying purposes, and access to interpretation of our data for scientific research. The YSGN is designed to monitor earthquakes of the entire Yellowstone volcanic system, including Yellowstone National Park and the nearby Hebgen Lake fault zone. The GPS stations provide continuous monitoring of the crystal deformation of the volcanically active Yellowstone caldera and surrounding areas. The GPS data are accessed routinely for use as base stations for park surveying needs. This integrated monitoring system provides real-time earthquake surveillance by a modern 22-station, 32-component, seismic network telemetered via FAA microwave links (at no cost to the project) to Salt Lake City, and digitally recorded at the University of Utah Seismograph Stations. The seismic data are accessible via the Internet from the University of Utah. Continuous GPS data are recorded at five sites (two stations are cooperatively operated with the USGS) and are processed at the University of Utah. The GPS data are archived at UNAVCO and accessible via the Internet. The USGS Volcano Hazards Program primarily funds this cooperative project with additional support form the National Park Service for fieldwork. The primary products for this project are earthquake catalogs, online availability of continuos GPS data, the services of a regional earthquake and GPS recording and information center, and timely release of unusual earthquake activity reports to the USGS and the NPS.

Findings: In addition to routine network operations, notable efforts during the report period included continued upgrading and maintenance of seismograph and GPS stations against the harsh winter conditions of Yellowstone. The tasks included: 1) continued installation of audio bandpass filters at relay sites to reduce interference; 2) replacement of aging radio transmitters and receivers throughout the network; 3) VCO system repairs and upgrades; 4) removing a seismic station PITT near Lake and relocating it to a site in an old gravel pit near Little West Thumb Creek; 5) upgrading the Norris station with broadband seismometers; and 6) installation of three dual-frequency GPS sites. Nineteen of the twenty-two stations of the Yellowstone seismograph network were visited for maintenance during the report period. The digital broadband seismograph station near the Madison Canyon has had long-term telemetry problems requiring several visits to the site. After a long process of elimination we found out that U.S. West telephone line had excessive noise. This was corrected and the station is working fine. Removed the broadband seismometers from Lake Butte and installed them at Norris for better geographic coverage of the caldera. Assisted the USGS-NEIC with maintenance of a cooperative U.S. National Seismograph Station (USNSN) located near Yellowstone Lake (LKWY). Sawelle Peak Repeater site - Made repairs to antennas damaged by winter and ice from 98-99 winter. Maintenance of the continuous recording, high-precision GPS station Lake and Mammoth. Installation of three continuously recording GPS receivers at Old Faithful, Hayden Valley, and White Lake. These stations along with two other stations provide much needed monitoring of ground motion of the YNP caldera. Data are automatically retrieved via satellite and dial-up telephone lines every 24 hours and then incorporated into the UNAVCO GPS archives. Analysis continued on the systematic determination of local magnitudes (M L) and M L station corrections using local USNSN, Montana Wood-Anderson station BUT and Utah broadband stations, for all coda magnitude (M C) 3.0 and greater earthquakes located in the Yellowstone region since January 1, 1994. Steps towards submitting 19 years of University of Utah short-period waveform data to the IRIS Data Management Center in SEED format, including: 1) use of IRIS's PDCC (Portable Data Collection Center) software; 2) compilation of a database inventory of instrument components for all stations in our network since digital recording began in 1981; and 3) compilation of system response information for all past and present stations in our network. Continued software development to integrate new digital data streams (REF, TEK, and USNSN) with existing analog data streams for routine analysis. Completion of a network inventory for the CNSS (see *www.cnss.org/NETS*) and major progress towards a comprehensive station inventory for the IASPEI handbook. Submission several times per day of earthquake catalog data for the Utah region to the Council of the National Seismic System's (CNSS) composite catalog. Assistance to the National Park Service with long-term plans for implementing volcano and earthquake hazard assessment and identifying manpower needs. Analysis of space-time variations of seismic source mechanisms and related stresses of Yellowstone reported in an M.S. thesis of Greg Waite. Discussions with the USGS, Menlo Park volcano seismology group regarding implementation of long-period event detection software (within Earthworm). Analysis of ground deformation of the caldera using GPS and its relation to faulting and earthquakes of the nearby Hebgen Lake fault zone reported in a M.S. thesis of Christine Puskas. Fabrication and design of particular items for all the above activities in our University of Utah electronic shop. Presentation of the findings and objectives of our research to as well as presentation of new information contained in the recent book *Windows into the Earth, The Geologic Story of Yellowstone and Grand Teton National Parks* By Robert B. Smith and Lee J. Siegel to NPS personnel.

Availability of data: All seismic waveform data archived by the University of Utah Seismograph Stations are available upon request (typically delivered to the user in SAC ASCII or binary format). Earthquake catalog data for the Utah region are available via anonymous ftp, *ftp.seis.utah.edu: pub/UUSS_catalogs*, or by e-mail request to: *request-quake@eqinfo.seis.utah.edu*, or via the Council of the National Seismic System's composite earthquake catalog, *http://quake.geo.berkeley.edu/cnss*. See also the University of Utah Seismograph Stations homepage at *www.seis.utah.edu*. GPS data are available through the Unavco GPS data archive site at: *http://archive.unavco.ucar.edu/cgi-bin/dmg/pss*. The contact persons for data requests are Susan J. Nava, Network Manager, e-mail: *nava@seis.utah.edu* or Dr. Robert Smith, e-mail: *rbsmith@mines.utah.edu*.

Project title:	**Ground Penetrating Radar Studies at Mammoth Hot Springs**
Principal investigator:	Dr. Marvin Speece
Phone number:	406-496-4188
Email:	*mspeece@mtech.edu*
Address:	Geophysical Engineering Montana Tech 1300 West Park Butte, MT 59701-8997
Additional investigators:	Laura Joss, William Sill

Objective: The purpose of this study was to identify possible geologic risks involved in future construction near Mammoth Hot Springs, Yellowstone National Park. Ground penetrating radar was used to help identify these geologic hazards.

Findings: In the Mammoth Hot Springs area of Yellowstone National Park, the surface rock is predominantly a hydrothermal variety of layered, porous limestone known as travertine. Limestone typically has low electrical conductivity making it ideal for ground penetrating radar (GPR) use. In the spring of 1997, GPR tests were conducted in three areas: 1) near the 1895 mail carrier's cabin; 2) near the Ice House; and 3) Opal Terrace. At the time, the first two sites were considered as possible locations for the Yellowstone Heritage and Research Center, while the third site was investigated because of concerns about the encroachment of Opal Terrace on the Executive House. Based on the success of these initial tests, a more detailed study was conducted at a two-acre area surrounding the mail carrier's cabin.

In these studies, penetration depths of over eighteen meters were observed in some of the GPR profiles. The profiles show: 1) buried utilities; 2) numerous, relatively continuous, travertine layers; and 3) possible cavities. A rapid loss in signal strength is observed at the bottom of most of these profiles. This lack of returning reflected energy at the base of the highly-reflective layered travertine package could be caused by the boundary between travertine and less reflective, more conductive, volcanic or sedimentary rocks that are likely found underneath the travertine in the area. Alternatively, the rapid loss in signal strength could be caused by a relatively high electrical conductivity that would be expected in rock saturated with mineralized water. GPR successfully imaged travertine layers in the Mammoth Hot Springs area and detected a possible subsurface cavity near the historic Executive House. GPR shows tremendous potential as a technique for evaluating the subsurface near thermal features throughout Yellowstone. These results were presented at the Sixth Yellowstone Interagency Science Conference held at Mammoth, Wyoming, September 16-17, 1999. No additional data were collected in 1999.

Project title: **Eruption History of the Sepulcher Formation as Determined by Geochemistry**

Principal investigator: Dr. Clyde Webster, Jr.
Phone number: 909-558-4548
Email: *cwebster@univ.llu.edu*
Address: Geoscience Research Institute
Loma Linda University
Loma Linda, CA 92350

Additional investigators: Harold Coffin

Objective: To use the geochemical analyses and statistical methods in the analysis of the breccia, rock, and ash samples from Yellowstone fossil forest located in the Specimen Creek area in an attempt to clarify the origin and history of the breccia flows, ash stringers, and the petrified trees that are located within these flows.

Findings: During 1999 three days were spent in the field verifying major fossil locations by GPS. No samples were taken during this time. Statistical analyses are almost complete for the entire area. Manuscript preparation is in progress.

Project title: **Tracing Fine Sediment Transport in Fluvial Systems Using Fallout Radionuclides**

Principal investigator: Dr. Peter Whiting
Phone number: 216-368-3989
Email: *pjw5@po.cwru.edu*
Address: Department of Geological Sciences
Case Western Reserve University
Cleveland, OH 44106

Additional investigators: Gerald Matisoff

Objective: Our objective is to investigate the erosion mechanisms of fine sediment and the transport characteristics of fine sediment in channels. Specifically, we aim to answer questions on the source and transport of fine sediment in the Yellowstone River drainage. We employ fallout radionuclides (^{7}Be, ^{137}Cs, ^{210}Pb) as tracers. ^{7}Be has a short half-life (53 days) which provides a marker for sediment recently delivered from the landscape. By monitoring stream sediment for the amount of ^{7}Be and other radionuclides, we can evaluate the fraction of sediment that has been recently delivered from the landscape as opposed to eroded from the stream bed, estimate transport distances for the fine sediment, and estimate residence times for sediment and adsorbed materials.

Findings: Our findings after one week of reconnaissance and analysis of limited samples collected during the reconnaissance show that the amount of ^{7}Be in soils is relatively uniform. Radionuclides are found in measurable quantities in the suspended sediment of the Soda Butte/Lamar/Yellowstone system. The amount of ^{7}Be in suspended sediments decreases downstream along Soda Butte Creek from values typical of the soil surface to very low values near the confluence with the Lamar River.